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Introduction

Tall timber buildings are increasingly on the agenda of architects, engineers and fire services around the world. New proposals for tall timber buildings appear on an almost weekly basis – some remain as plans, while others get built. Regulations controlling fire safety are frequently cited as a primary barrier to the future proliferation of tall timber buildings. In response to this there has been a substantial research effort around the world. The National Fire Protection Association, National Institute for Standards and Technology, and FPInnovations [1]–[3] have all written or commissioned extensively referenced reports that describe the state-of-the-art for the design of timber to withstand the effects of fire. Objectives have been defined, resources have been committed, and researchers have begun to investigate.

At the recent World Conference on Timber Engineering (WCTE) in Vienna [4] and the Structures in Fire (SiF) Conference in Princeton [5] it became clear that two distinct schools of thought have emerged regarding how structural fire safety may be achieved in tall timber buildings.

The first approach is rooted in demonstrating compliance with existing or updated fire resistance rating requirements, by undertaking standard fire resistance tests. This approach assumes that there are no fundamental differences between timber, steel, or concrete buildings; it simply uses the existing fire resistance design framework, which has been applied and developed for almost a century in the design of tall steel and concrete buildings. The second approach recognises the differences between combustible and non-combustible construction materials and explicitly requires that a structure should resist burnout – this challenges the validity of the existing fire resistance framework as a means to achieve adequate structural fire safety.

Design for Burnout

The fire resistance ratings in contemporary design codes were created with the intention that a structure would maintain its loadbearing capacity for as long as a fire could burn, until all the fuel in the compartment was consumed – this is *design for burnout* [6], [7].

At the time that 'fire resistance' was developed, the fire dynamics of compartment fires were sufficiently well characterised to allow conclusions to be drawn about what fire resistance rating was required for a structure to survive burnout. Over the years, this comparison has been continually refined [7], and it has been found that compartment fire dynamics can be well represented as a function of compartment geometry, thermal properties, ventilation and fuel load. These approaches were developed using non-combustible structural materials; it was therefore assumed that the fire behaviour was independent of the structural material which, by definition, could not become involved in the fire. This assumption remains embedded within existing regulatory fire resistance requirements.

However, when combustible structural materials are used, the resulting fire dynamics are no longer independent of the structural design; there is a *coupled* interaction between the structural and fire engineering design. This interaction introduces three issues that seriously undermine the usefulness of the existing fire resistance framework in achieving structural adequacy:

1. Current fire resistance rating requirements do not account for the contribution that a combustible structure makes to the intensity and duration of a fire; consequently, existing fire resistance requirements do not guarantee structural survival.
2. Current fire resistance ratings do not guarantee that combustible structural elements will cease to burn once the furnishings are consumed; consequently, existing fire resistance ratings do not guarantee structural survival.
3. During the standard fire test, the sample properties and contribution of combustion gasses from exposed CLT linings means that the test does not guarantee equivalent thermal exposure between different construction types.

Consequently, it is not possible to define a meaningful period of fire resistance for an exposed timber element within the existing fire resistance framework. Any design that includes exposed structural timber elements and does not consider the coupled interaction between the structure and the fire leaves structures at risk of unwanted failures.

Burnout of CLT

For CLT to be safely used as the primary structural frame for tall buildings, it must be demonstrated that burnout can be achieved prior to structural failure. Fortunately, mass timber will not burn without an external energy source [8]. Therefore, if all the fuel within a compartment (i.e. the furnishings) have been consumed, it is possible for the timber cease burning – this is termed auto-extinction.

A number of researchers internationally have undertaken investigation of the conditions required for auto-extinction, and there is a growing understanding of the interactions between the structure and the compartment fire dynamics. Early findings are encouraging. Medium and large scale experiments around the world have demonstrated that, under certain conditions, auto-extinction can be achieved; these experiments have typically involved relatively few exposed CLT faces within a compartment, comparatively low fuel loads, and minimal “fall off” of timber layers. Conversely, where there has been a larger number of exposed faces and significant lamella “fall off” has occurred, secondary flashover (or sustained burning) has been observed in many cases.

Research has begun to quantify the contribution of exposed mass timber to the heat release rate of a compartment fire. Even small and medium scale compartment testing [9], [10] has demonstrated that exposed CLT can make a very substantial contribution to both the total heat release rate, and the total fuel consumed during a fire. These experiments have also shown that minor changes in the compartment arrangements can be exploited by designers to promote auto-extinction.

Large scale tests by The University of Edinburgh [11][12], and The University of Queensland [13] (all documented in papers to be presented at the forthcoming IAFSS Symposium in Lund) have shown that changes in the arrangements or the compartment fuel load can either deliver a compartment that burns out, or result in sustained burning of the timber structure. Currently, the interaction between these phenomena remains under investigation. Once the governing physics is understood, it will be possible to identify the design decisions necessary to allow the specification of buildings that will achieve auto-extinction.

Growth to flashover and continued burning of CLT linings during a compartment fire
(images courtesy of the University of Edinburgh)

Progression to burnout and auto-extinction of a CLT wall following a compartment fire
(images courtesy of the University of Queensland)

Figure: (a) test at the University of Edinburgh where continued burning was observed [11]; and (b) test at the University of Queensland where auto-extinction was observed [13]

Conclusion

It is possible to design timber buildings safely using knowledge of fundamental fire dynamics and its interaction with the structure. The two current approaches identified for delivering fire safety in tall timber buildings are not mutually exclusive. For buildings with exposed CLT, there is now overwhelming evidence that compliance with the existing fire resistance framework is not necessarily sufficient to guarantee that legislative fire safety goals will be met. It may be possible, under the current fire resistance framework/mindset, for designers to obtain regulatory approval without properly addressing the issue of burnout.

However as timber buildings get ever taller, the consequence of failing to design for burnout will become greater and the risk to life, property, and the environment also becomes greater. Therefore, engineers who knowingly fail to address the issue of burnout are violating the requirements of the SFPE code of ethics.

Every material presents fire risks, but the fire safety engineering community manages them in different ways, depending on the specific hazards and consequences of failure [14]. For CLT construction it is possible to meet the existing regulatory requirements while ensuring that a building is also able to achieve burnout; this simply requires engineers to carefully consider the risks of this new construction type, and to use the best available knowledge and understanding to determine how these must be managed during design, implementation, and operation.

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